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ADVANCED HIGH ELECTRON MOBILITY TRANSISTOR (HEMT) MONOLITHIC MILLIMETER-WAVE INTEGRATED CIRCUIT (MMIC) CIRCUITS FOR MILLIMETER- AND SUBMILLIMETER-WAVE POWER SOURCES

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This paper focuses on InP-based, HEMT Monolithic Millimeter-wave Integrated Circuit (MMIC) power amplifiers for applications to heterodyne receivers, transmitters, and communication circuits. Recently, JPL has developed several HEMT MMIC circuits using HRL Laboratories' 0.1 uμ InP HEMT technology with unprecedented high frequency performance and output power. Results include an 80 GHz bandwidth power amplifier to 145 GHz, a 15-25 mW amplifier to 170 GHz and a HEMT active doubler to 300 GHz, the highest frequency HEMT doubler circuit reported to date. Included here is a description of the design and testing of the circuits, and a discussion of the methods used in measuring MMICs above 200 GHz. These circuits are particularly useful in local oscillators for heterodyne receivers at THz frequencies.

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ADVANCED HEMT MMIC CIRCUITS FOR MILLIMETER- AND SUBMILLIMETER-WAVE POWER SOURCES

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ABSTRACT

This paper focuses on InP-based, HEMT Monolithic Millimeter-wave Integrated Circuit (MMIC) power amplifiers for applications to heterodyne receivers, transmitters, and communications circuits. Recently, we have developed several HEMT MMIC circuits using HRL Laboratories' 0.1 um InP HEMT technology with unprecedented high frequency performance and output power. Our results include an 80 GHz bandwidth power amplifier to 145 GHz, a 15-25 mW amplifier to 170 GHz and a HEMT active doubler to 300 GHz, the highest frequency HEMT doubler circuit reported to date. We will report on the design and testing of the circuits, and discuss the methods involved in measuring MMICs above 200 GHz. These circuits are particularly useful in local oscillators for heterodyne receivers at THz frequencies.

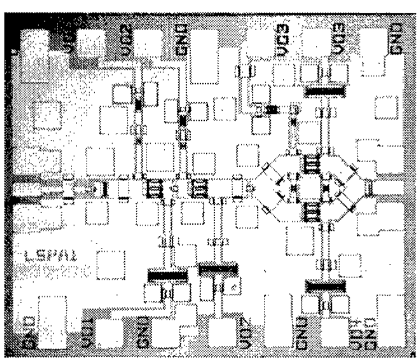
INTRODUCTION

We first describe several MMIC power amplifier and active multiplier chips, fabricated in HRL Laboratories' 0.1um InP High Electron Mobility Transistor (HEMT) technology. Previous work in the area of power amplifiers includes many excellent results[1,2] at W-Band (75-110 GHz), and there are many applications to drivers for local oscillators in heterodyne systems using these chips. In this paper, we discuss the next generation of MMIC power amplifiers, with HEMT MMIC results up to 300 GHz. We also discuss the challenges of measuring MMICs at high frequencies and present the measurement results.

ADVANCED HEMT MMICS

Wideband Medium Power MMIC Amplifiers

First, we present the results of an 80% bandwidth medium power amplifier chip, the details of which are discussed in Ref 3. All of the amplifiers presented here make use of grounded co-planar waveguide topology (CPWG), and were designed using MMICAD and HP MDS. The first amplifier, referred to as PA1, employed three stages (Figure 1). The first two stages used HEMTS having 4 gate fingers 37 microns wide, and the third stage combined two 4x37 HEMTs in parallel. The total device periphery in the output stage is 300 μm. Typical device breakdown voltage was 4 V. We packaged this amplifier in a WR8



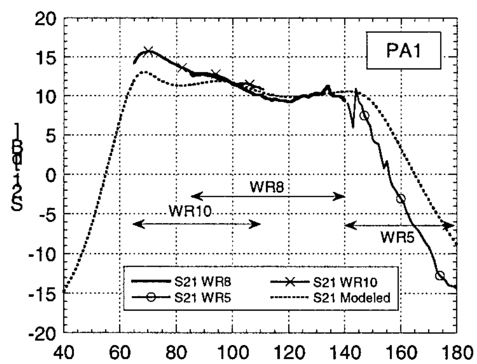


Figure 1: Chip photo and measured data for a > 80 GHz wide, 65-150 GHz InP medium power amplifier MMIC. Data was measured in three waveguide bands.

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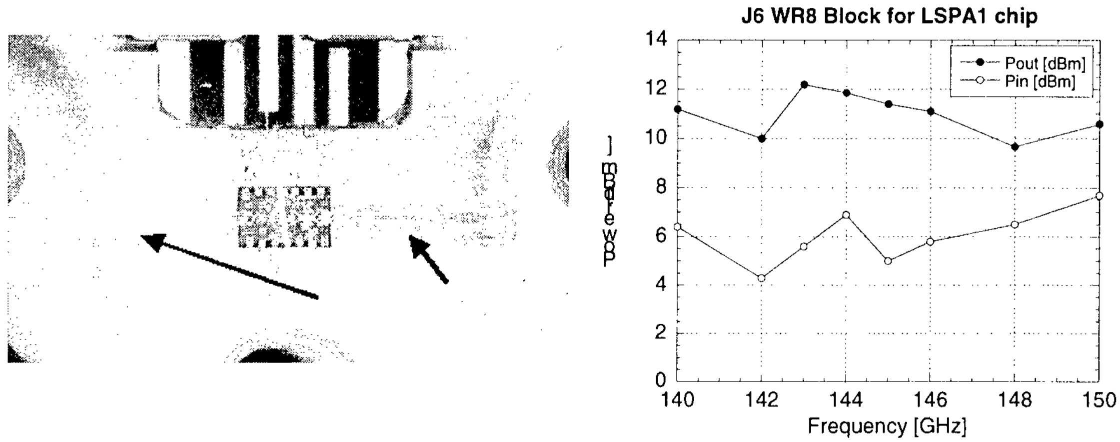


Figure 2: Module photo at left showing MMIC of figure 1 and probe transitions to waveguide (arrows). At right is the measured power from the module (approximately 10 mW or more from 140-150 GHz).

waveguide housing (Figure 2), and measured it for output power characteristics. The output power was found to be between 10-30 mW over the entire bandwidth, with the 140-150 GHz band shown in Figure 2. Such an amplifier would make a useful gain stage for a wide-band local oscillator.

MMIC Power Amplifier to 170 GHz

In addition, we report on a second medium power amplifier chip from 140-170 GHz, thus far the highest frequency power amplifier chip reported to date [4]. The chip exhibits 10 dB of small signal gain from approximately 144-170 GHz, with input and output return losses of 10 dB at 165 GHz. From 140-170 GHz, 15 to 25 mW (11.8 – 14 dBm) of output power is achieved across the band. Modeling of the HEMT devices suggests that power amplifier designs are possible to 300 GHz. Thus far, new designs are currently being fabricated to test chip performance up to 200 GHz. Current work involved packaging the chip in a WR5 waveguide housing, similar to Figure 2.

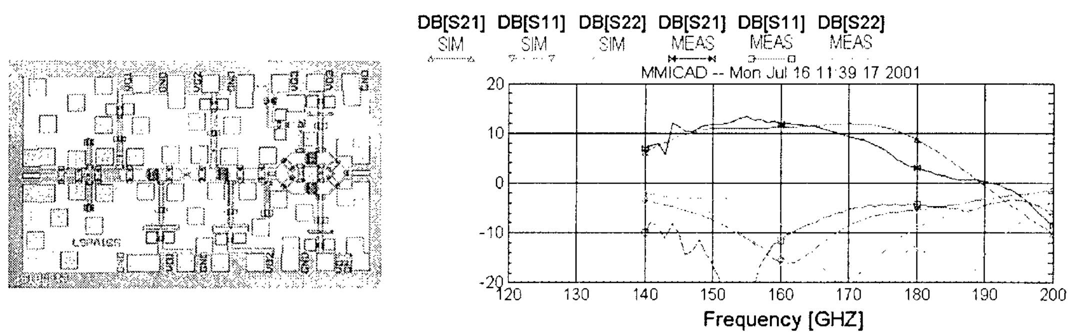


Figure 3: Left: Chip photo; Right: measured(MEAS) and simulated (SIM)S-parameter data from a 15 mW medium power amplifier to 170 GHz.

HEMT MMIC Doublers

Active HEMT doublers have the potential for higher conversion efficiency than Schottky diode doublers. They also have the advantage of being integrated with oscillators and amplifiers on a MMIC. Previous HEMT doublers include a 164 GHz HEMT doubler with only 2 dB of conversion loss and 5 dBm of output power [5]. The highest frequency HEMT doubler previously reported is a 180 GHz, 250 μW chip with 6 dB of conversion loss[6]. We now report on a HEMT MMIC doubler with approximately 1% conversion efficiency at 292 GHz, the highest frequency of operation for a HEMT doubler circuit to date. The doubler chip layout is shown in Figures 4 and 5. The input was matched to the fundamental frequency of 150 GHz, while the output matching was intended to suppress the fundamental and match to the second harmonic.

MMIC MEASUREMENTS UP TO 300 GHZ

Figure 4 shows the schematic of the measurement system for the 300 GHz doubler. A BWO was used for the W-band source, and was followed by a multiplier from Millitech from 140-170 GHz. Waveguide wafer probes from GGB Industries were attached to the Millitech doubler and provided a means of getting power to the MMICs. The power amplifier chip of Figure 3 was wire-bonded to the active HEMT doubler, in order to provide more input power to the final doubler than was available from the multiplier. The output of the doubler was then fed into a second waveguide wafer probe, and a power meter was used to detect the power passing through the wafer probe. A section of WR3 waveguide between the final doubler chip and the power meter ensures that power measured is not less than 173 GHz, so that no fundamental power can leak through. Figure 5 shows the results of doubler testing. It is imperative that the fundamental frequency (which may radiate from wire bonds in the power amplifier, or leak through the doubler) be prevented from reaching the power meter, in order to separate out power from the second harmonic in the doubler. We have achieved nearly 1% conversion efficiency and 81 μW of power at 292 GHz, with at least 40 μW at 300 GHz.

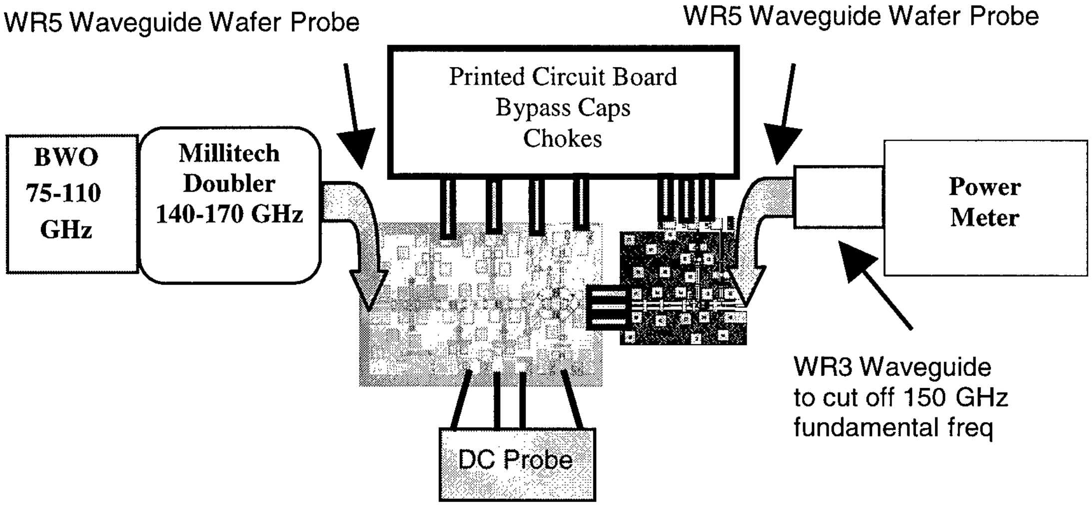
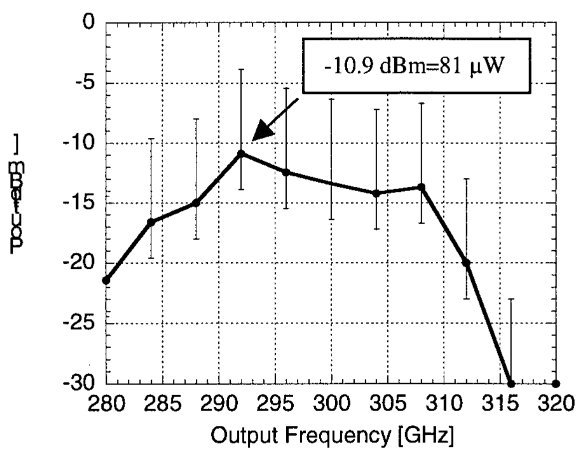


Figure 4: *Test setup of power measurements on-wafer at 300 GHz. Power amplifier chip is wire-bonded to the HEMT doubler. The output of the doubler is fed into a waveguide wafer probe, the fundamental frequency is cut-off by a section of WR3 waveguide, and a power meter is used to detect the power passing through the wafer probe.*



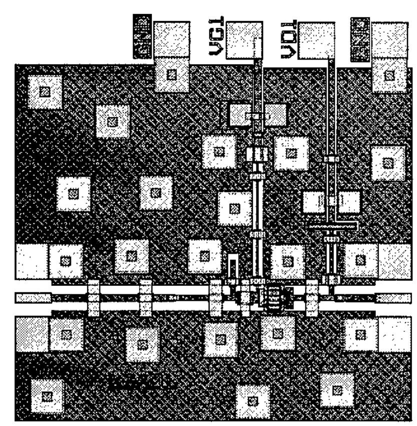


Figure 5: *Measured output power from a HEMT doubler on-wafer. Error bars indicate the uncertainty in the waveguide wafer probes at 300 GHz. At right is chip layout.*

Wafer probing is very challenging at these frequencies, because to date no wafer probes exist which are optimized for 300 GHz performance. However, we are working with GGB Industries to develop the first WR3 waveguide wafer probe, which we will characterize with Oleson Microwave's WR3 Vector Network Analyzer frequency extension modules. In any case, for a real subsystem, wafer probing is limited to the testing area, and a permanent solution to interfacing 300 GHz MMICs with waveguide-compatible technology must be found. Several avenues of research are being pursued, one of which is an integrated E-plane probe technology, such as that developed by S. Weinreb in [7], or a quasi-Yagi antenna approach, pioneered for MMICs in [8]. Approaches like these can eliminate lossy wire-bonding and reduce the need for higher frequency wafer probes.

FUTURE WORK

Wide-band, medium power amplifiers and active doublers such as those described in this paper may be useful for the local oscillators in large scale telescopes such as the Atacama Large Millimeter Array, and follow-on missions to SWAS and the Herschel Space Observatory's HIFI instrument. These MMIC chips represent a small fraction of the potential of InP HEMT MMIC technology in the future. Based on the extracted device models, 300 GHz MMIC amplifiers should be possible with this technology, and improvements to the HEMT technology should result in power amplifiers well into submillimeter-wavelengths. Advances in transition and planar antenna design with integration onto the MMICs will enable ease of testing, and permit submillimeter waveguide-compatible amplifiers for local oscillator subsystems in future astrophysics instruments.

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